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A three cadet design team from the Department of Systems Engineering at USMA investigated changes to the current Armor Battalion force structure as part of a combined effort to preserve to overall effectiveness of the armor unit in a cost effective manner. The initial stages of problem definition led to the identification of an initial effective need of developing a rapidly deployable system capable of effective armored combat. Further refinement of this effective need statement, prior to entering the systems modeling and analysis phase of the systems engineering design process, led to the following specific effective need statement : To evaluate the overall effectiveness of the armor battalion organizations minimizing decreased effectiveness caused by down-sizing the force. Smaller organizations would have the added benefit of increased strategic deployability.

The decision to do analysis of the force structure stemmed from the fact that the current main battle tank is proven combat effective. The current main battle tank is proven combat effective. The current armor battalion consists of 58 M1A1/2 Abrams tanks. By taking any number of vehicles out the armor battalion, some loss in combat effectiveness is to be expected. However, if the need to reduce cost still remains, it is apparent that minimizing the decrease in combat effectiveness is very important. Strategic mobility plays a major role in the need to reduce the number of vehicles in the armor battalion. By reducing the number of tanks in an armor battalion, the cost to deploy, the time to deploy and the assets needed to deploy are all decreased. Altering the configuration of the armor battalion directly effects three objective areas: 1) Cost Savings 2) Combat Effectiveness and 3) Strategic Deployability. Our goal is to target the fine line that separates cost savings from decreased combat effectiveness.

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Armor Battalion Force Structure in Force XXI

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Armor Battalion Force Structure in Force XXI

A capstone systems engineering design project

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PREFACE

The enclosed research is the result of a semester long, research and analysis project examining the effects of smaller armor battalion configurations on overall effectiveness. The study was conducted by a team of three cadets, under the direct supervision of three faculty members at the Department of Systems Engineering at the U.S. Military Academy. The Janus 6.0 simulation used an unclassified database and scenarios were based on two approved High Resolution Scenarios (HRS). The tactics and employment were developed and well rehearsed under the guidance of three combat arms (one armor, two field artillery) Majors, all with combat experience. The terrain databases are realistic and the same used in the classified studies.

While the system databases used were not classified, we believe they closely replicated the combat systems specifications. Also, while the direct performance results may not be identical to those done in a classified environment, we are confident that the deltas between the alternatives are truly indicative of actual differences.

The enclosed technical work and briefing is edited cadet academic work and does not represent official US Army data, results, policy positions or recommendations.

We want to thank the officers assigned to the Deputy Chief of Staff for Operations, especially LTG Shinseki and LTC Donnelly and the Assistant Secretary of the Army for Financial Management and Comptroller for their sponsorship of this cadet capstone systems engineering design project at the United States Military Academy

EXECUTIVE SUMMARY

A three cadet design team from the Department of Systems Engineering at the U.S. Military Academy investigated changes to the current Armor Battalion force structure as part of a combined effort to preserve the overall effectiveness of the armor unit in a cost effective manner. The initial stages of problem definition led to the identification of an initial effective need of developing a rapidly deployable system capable of effective armored combat. Further refinement of this effective need statement, prior to entering the systems modeling and analysis phase of the systems engineering design process, led to the following specific effective need statement: *To evaluate the overall effectiveness of the armor battalion organizations minimizing decreased effectiveness caused by down-sizing the force.* Smaller organizations would have the added benefit of increased strategic deployability.

The decision to do analysis of the force structure stemmed from the fact that the current main battle tank is proven combat effective. The current armor battalion consists of 58 M1A1/2 Abrams tanks. By taking any number of vehicles out of the armor battalion, some loss in combat effectiveness is to be expected. However, if the need to reduce cost still remains, it is apparent that minimizing the decrease in combat effectiveness is very important. Strategic mobility plays a major role in the need to reduce the number of vehicles in the armor battalion. By reducing the number of tanks in an armor battalion, the cost to deploy, the time to deploy, and the assets needed to deploy are all decreased. Altering the configuration of the armor battalion directly effects three objective areas: 1) Cost Savings 2) Combat Effectiveness and 3) Strategic Deployability. Our goal is to target the fine line that separates cost savings from decreased combat effectiveness.

The design team analyzed four different armor battalion force structures. The first force structure evaluated was the current structure of 58 tanks, organized into four companies of fourteen tanks and two headquarters tanks. The three other force structures were derived from this base case structure, focusing on reducing the number of tanks, while maintaining as much similarity to the existing structure as possible. The team attempted to keep the basic structure of the armor battalion in order to preserve company and platoon fighting doctrine as much as possible. The three other structures examined were a 46 tank battalion made up of four companies of eleven tanks and two headquarters tanks, a 44 tank battalion made up of three companies of fourteen tanks and two headquarters tanks, and a 35 tank battalion made up of three companies of eleven tanks and two headquarters tanks. The rationale for these different force structures included the removal of one tank per platoon within the battalion, one company per battalion, or one tank per platoon and one company per battalion respectively.

The force structure alternatives were then analyzed and evaluated using simulations run in Janus 6.0. Prior to running the simulations, a design of experiments was formulated around a four factor, full factorial design. The four factors were observed and analyzed in order to

determine what contributes most to the effectiveness of the armored battalion: number of tanks per company, number of companies in the battalion, the type of main battle tank used, and the scenario. After identifying on the four factors for the experiment, we determined the high and low values for each factor, shown in Table #1.

The design experiment blocked on the scenario factor in order to limit the effects of external factors surrounding the change in terrain, numbers of enemy versus friendly losses, and tactical changes in the way the defense and offense were fought. By blocking on the scenario, its confounding effects on the other factors would be minimized.

Factor	High (+)	Low (-)
# tanks	14	11
# companies	4	3
tank type	M1A1	M1A2
scenario	defense	offense

Table 1. Experimental Factor Levels

Three measures of effectiveness were identified to evaluate and compare the different force structures. The first MOE was force exchange ratio (FER) which is a ratio of red losses verses blue losses based on initial strengths throughout the battle. The second MOE was the average time to attrit the enemy to 50%. The third MOE was the average range of engagement.

The team then set up and tested a Janus scenario for both the offense and the defense. The defensive scenario was set in Northeast Asia with two enemy brigades attacking against one friendly brigade in prepared area defense (based on HRS 31). The offense was set in Southwest Asia with the same friendly brigade attacking against one enemy brigade in a prepared defense (based on HRS 58). Once both scenarios were scripted, a series of pilot runs were made with both scenarios to ensure tactical soundness and model validity. The data from these pilot runs was collected and analyzed based on our factors and the measures of effectiveness identified above. The analysis of this data, and the variation in the data allowed for the calculation of the number of runs needed for each data point to achieve the desired confidence level of 0.95.

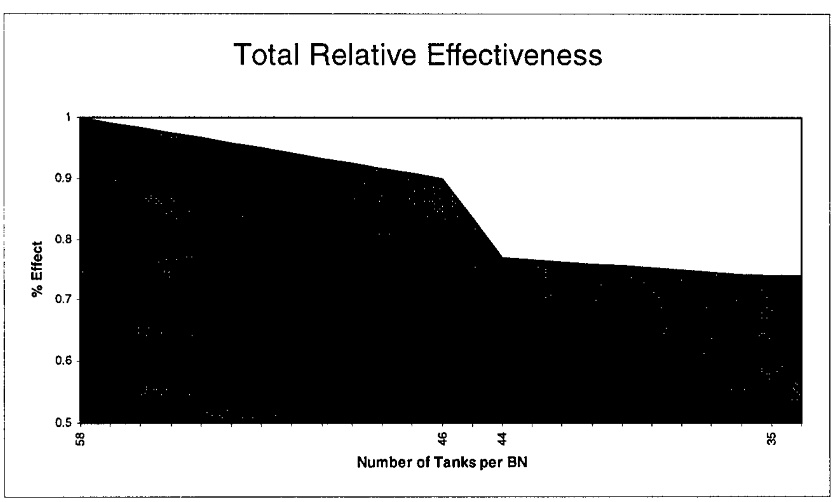


Figure 1. Total Relative Effectiveness

Calculations yielded that 5 runs per data point was enough to achieve significance with an alpha value of 0.05.

The data analysis of eighty simulation runs led to the conclusion the best way to reduce the number of tanks in the armor battalion is to reduce to four companies of eleven tanks. This conclusion was based on a total relative effectiveness calculation, which accounted for all of the factors within the design and the appropriate weight for each. The chart in Figure 1 illustrates a significant degradation in relative effectiveness occurring between the 46 and 44 tank battalion. We believe that this is primarily due to the loss of the fourth company-level command and the degradation in flexibility and control, rather than just the loss of two tank systems per battalion.

Although this is only a reduction of two tanks, the change in force structure between three and four companies is quite significant. Furthermore, the conclusion is not sensitive to the weights assigned to the different MOEs. The alternative with four companies of eleven tanks was dominant over the other alternatives (save the base case of 58 tanks).

Additionally, the cost analysis further supports the conclusion of four companies of eleven tanks. Figure 2 illustrates how much more it would cost to bring the 46 tank battalion up to the relative effectiveness of the current 58 tank battalion.

In conclusion, the armor battalion will suffer a loss in overall effectiveness if its number of tanks is reduced. However, the analysis has shown that by reducing the size of the Armor Company to eleven tanks, rather than eliminating an entire company from the battalion, this reduction in performance can be minimized. All conclusions were based on statistically significant observations from the simulation study.

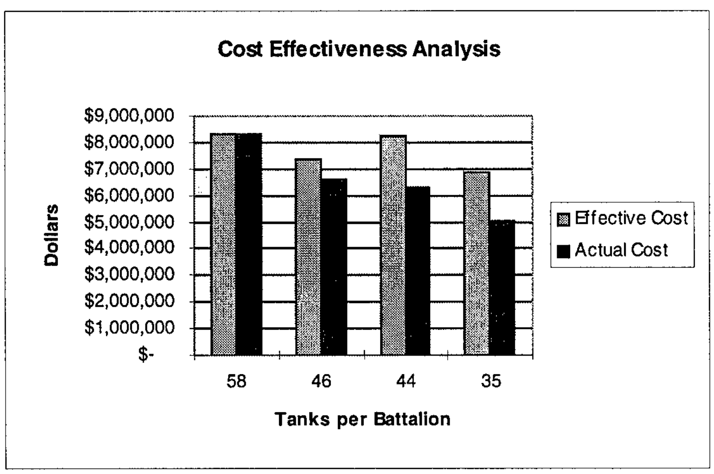


Figure 2. Cost Effectiveness

ALTERNATIVES

In developing alternative force configuration designs, it was desired that any alternative should have a minimal effect on doctrine and training at the battalion, company, platoon and section level. The logical points to accomplish force reduction was to eliminate one entire company from the battalion (going from 4 to 3), eliminating one tank from each platoon, thereby cutting a company from 14 to 11 tanks, or doing both and cutting a company and a tank from each platoon. The alternative of cutting a platoon from each company was not considered since such a reduction would significantly reduce the company's combat power and tactical flexibility.

The armor force configurations tested are:

A) 4 Companies of 14 M1 tanks each (58 tanks) [the Base-Case]
B) 4 Companies of 11 tanks (46 tanks)
C) 3 Companies of 14 tanks (44 tanks)
D) 3 Companies of 11 tanks (35 tanks)

This structure allowed logical progression into an analytical design of experiments that would allow quantifiable comparisons of the factors: whether it is the number of companies, size of the companies or a combination that had the greatest overall effect on the experiment. The difference in effectiveness between M1A1 and M1A2 tanks was also examined.

DESIGN OF THE EXPERIMENT

After determining that a factorial design best fit the needs of the armored force structure problem, the next step was to identify the key factors involved with force structure and unit effectiveness on the battlefield. Guidance from the client, combined with the determined effective need of the client, led to the identification of four factors. These four factors account for the main issues concerning force structure: the type of main battle tank in the battalion, the number of companies in the battalion, the number of tanks per company, and the type of operation conducted. Two levels for each factor were then identified in order to model the different force structures the client was considering. Table 2 shows the two levels of each factor.

Factors	Low (-)	High (+)
Type of Tank	M1A1	M1A2
# Companies	3	4
# Tanks	11	14
Scenario	Defensive	Offensive

Table 2: Factors

After identifying the four factors for the experiment, measures of effectiveness were identified for the purpose of comparing the different force structures. It is these measures of effectiveness that will ultimately rank order the main effects of the experiment and determine which factor contributes to the overall effectiveness of the armor unit and which element of the force is statistically the most significant in determining future armored force structure. Considering the possible impacts of force structure in a war time situation, measures of effectiveness such as force exchange ratio and time to attrit the enemy to specified levels of ineffectiveness emerged as the appropriate criteria on which to weigh and compare the different force structures.

A factorial design for an experiment with four factors yields 16 possible data points for investigation. Table 3 summarizes the 16 different data points generated using the factorial design method. Note that this particular case lent itself for blocking on the fourth factor. The decision to block on scenario was made to ensure the environment did not affect the factors, since the different scenarios called for different tactics, fought on different terrain, with different objectives. These changes in environment could affect the factors if not taken into account by blocking. Additionally, blocking this factor allows for the comparison of measures of effectiveness across the blocks without further confounding on the actual factors within the experiment.

Run / Factor	M1A1 / M1A2	3 or 4 Companies	11 or 14 Tanks	Defense/ Offense
1	M1A1	3	11	Defense
2	M1A2	3	11	Defense
3	M1A1	4	11	Defense
4	M1A2	4	11	Defense
5	M1A1	3	14	Defense
6	M1A2	3	14	Defense
7	M1A1	4	14	Defense
8	M1A2	4	14	Defense
9	M1A1	3	11	Offense
10	M1A2	3	11	Offense
11	M1A1	4	11	Offense
12	M1A2	4	11	Offense
13	M1A1	3	14	Offense
14	M1A2	3	14	Offense
15	M1A1	4	14	Offense
16	M1A2	4	14	Offense

Table 3: Factor Settings

JANUS SCENARIOS

The cadet design team constructed an offensive and defensive brigade task force scenario in Janus 6.0. These scenarios were based on the terrain and force structure of High Resolution Scenarios 31 (Northeast Asia, Defense), and 52 (Southwest Asia, Offense). In both scenarios, a single system basic load of ammunition and fuel was used, and the battle recorded for 2 hours. Random numbers and starting seeds were controlled, allowing direct comparison of simulation runs with different configurations. Analysis of the variance in trial runs for the most heavily weighted measure of effectiveness (Force Exchange Ratio) yielded that five runs of each design point would be sufficient to achieve a level of confidence of 95%.

The two scenarios, Northeast Asia and Southwest Asia, took place in vastly different terrain. The Northeast Asia scenario took place among rolling hills and obstructed lines of site. Engagement ranges and the usable maneuver areas in this scenario are greatly reduced. The rugged terrain not only poses problems for the offensive forces, but it can provide benefits for both the defense and offense as well. The hills and uneven terrain can protect the movement of the offensive forces from direct fire. Similarly, the uneven terrain can provide natural obstacle and possible defilade positions for a prepared defense.

On the other hand, the Southwest Asia scenario took place in a desert environment. As a result, the terrain is virtually flat and engagement ranges are greatly extended. Also, the terrain does not restrict any avenue of approach determined by the maneuver force. The flat terrain, however, can lead to problems in either the offensive or defensive forces. For the offense, there is little terrain to mask movement. With the defense, the lack of terrain features does not allow natural obstacles to halt the advance of the enemy.

Southwest Asia: Offensive Scenario

INTRODUCTION

The Southwest Asia Offense (based on High Resolution Scenario 52) is a brigade deliberate attack on a Red Force brigade in a prepared defense in Southwest Asia.

FRIENDLY FORCES

Friendly forces consist of a full armored brigade with appropriate artillery assets and close air support (CAS). Blue Forces are split up into two balanced forward task forces abreast and one in trail. One forward balanced task force is armored and the other is mechanized. The trail task force is a pure armored battalion. We split the Blue Forces up into five specific task forces that will allow us to conduct the offensive more effectively with maximum command and control. Blue forces have the capabilities to deploy all of the following weapons and vehicles:

Task Force Designation	Vehicle Type	Number of Vehicle Type Used
1	M1A1/2	30
1	M2 Bradley	28
1	FIST-V	7
1	HMMWV/50C	15
1	M106A1	6
1	D7 Dozer	1
1	ACE	3
2	M1A1/2	28
2	M2 Bradley	30
2	HMMWV/50C	15
2	M106A1	6
2	CEV	4
2	FIST-V	5
2	D7 Dozer	1
2	ACE	3
3	M1A1/2	58
3	M106A1	6
3	FIST-V	8
3	D7 Dozer	1
3	ACE	3
4	M109A3 Paladin	72
4	MLRS	36
4	FIST-V	3
5	Avenger	12
5	Apaches	12
5	BSFV	8
5	A-10	4
5	M3	12

Table 4: SWA Blue Forces

ENEMY FORCES

The threat maneuver forces are occupying three defensive battle positions: two forward and one in reserve. The two forward task forces are armored battalions with an attached mechanized infantry company. The reserve task force is an armored company. Enemy forces are dug in. As a result, all vehicles in the forward two battle positions are in defilade. Battle Position 1, is protected by a complex obstacle belt consisting of minefields and tank-ditches. The Red Forces have the following weapons and vehicles in their prepared defense.

Task Force Designation	Vehicle Type	Number of Vehicle Type Used
1	T-72	82
1	BMP-2	56
1	BTR-60	6
1	BRDM-AT	8
1	RPG-9	18
1	SA-13	23
1	ZSU-23-4	9
1	Hokum	2
1	120mm Mortar	14
1	2S6	12
1	MLRS	6
2	T-72	82
2	BMP-2	56
2	BTR-60	6
2	BRDM-AT	8
2	RPG-9	18
2	SA-13	23
2	ZSU-23-4	9
2	Hokum	2
2	120mm Mortar	14
2	2S6	12
2	MLRS	6
3	T-72	24
3	BMP-2	10
3	BRDM-AT	3
3	RPG-9	18
3	SA-13	13
3	ZSU-23-4	6
3	Hokum	3
3	120mm Mortar	14
3	2S6	12
3	MLRS	6

Table 5: SWA Red Forces

CONCEPT OF THE OPERATION

The mission for the Blue Forces is to defeat the northern-most forward enemy battle position and their armored reserve. During the attack, the enemy must not be able to retreat or reconsolidate. We expect the enemy to counterattack once their forward battle positions are defeated. The attack is conducted in four phases.

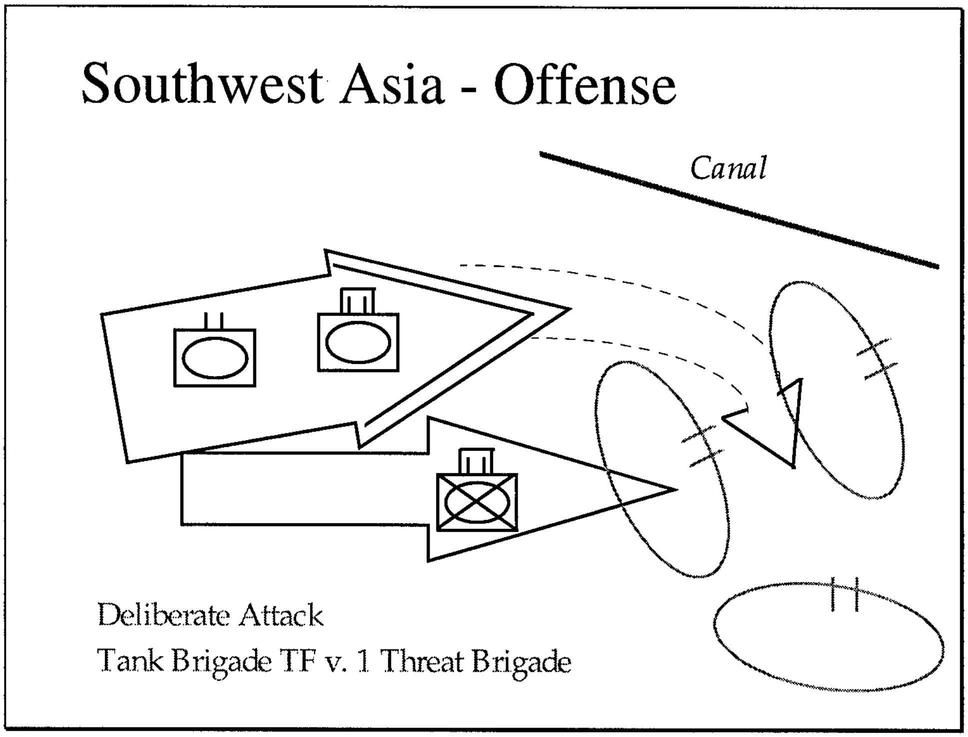


Figure 2: Offense Scenario SWA

Phase I: Blue Forces will initiate the attack with A-10s and Apaches attacking each of the enemy battle positions. Also, heavy artillery bombardments from 72 Paladin tubes and 36 MLRS launchers will prepare the threat defensive positions for the attack. The artillery coupled with the close air support(CAS) will help to pin down the enemy while the maneuver forces closes.

Phase II: The next step is to conduct the actual assault. Task Force 2, which is mechanized heavy, will move directly east and conduct a diversionary attack on Battle Position 1, the northern-most position. In the meantime, Task Forces 1 and 3 will conduct the main assault on the northern flank of Battle Position 1. Blue scouts from Task Force 1 make contact with the Red obstacles and wait for the breach. The armored task force and the pure armored brigade send up engineer assets to breach the obstacles.

Phase III: The mechanized heavy task force, Task Force 2, moves onto and clears Battle Position 1. Task Force 2 will then orient their fires south to prevent the enemy counter-attack coming from Battle Position 2. At the same time, Task Forces 1 and 3 move across Battle

Position 1 and expect to meet a counter-attack from the enemy reserve units in Battle Position 3. While Battle Position 1 is cleared, artillery will lay FASCAM minefields between Battle Positions 1 and 2 to delay enemy counter-attacks and enemy withdrawal.

Phase IV: After clearing Battle Position 3, Task Forces 1 and 3 will turn and move south to clear Battle Position 2. Once all three battle positions are cleared, Blue forces consolidate and reorganize on the objectives in preparation for an enemy counter-attack.

Northeast Asia - Defense Scenario

INTRODUCTION

High Resolution Scenario (HRS) 31 is a deliberate attack by the Red Forces against a prepared Blue defense in Northeast Asia (NEA). HRS 31 was originally slated to be an offensive scenario for Blue forces; however, under guidance from the client we adjusted the scenario placing Blue forces on the defensive. The scenario models a two brigade threat attack on a one brigade friendly prepared defense.

FRIENDLY FORCES

Friendly forces consist of a full armored brigade task force with appropriate supporting units such as artillery, air defense, close air support, and engineers. Blue forces are split into five battalion task forces allowing us to set up our defense more effectively and maintain realistic force structures. The front line defense consists of two balanced task forces abreast with one in reserve. The two front line task forces consist of one armored task force and one mechanized task force. The reserve task force is a pure armored battalion. The fourth and fifth task forces comprised our supporting elements. Blue forces have had substantial time to dig in their vehicles. As a result, all vehicles in the forward two battle positions are in defilade. The engagement area forward of the two balanced task forces are protected by a complex belt of obstacles consisting of minefields, tank ditches, and smoke pots. The table below shows all weapons and vehicles available for the Blue defense in NEA and which task force they are assigned. The numbers correspond to a full 58 tank battalion.

Task Force Designation	Vehicle Type	Number of Vehicle Type Used
1	M1A1/2	30
1	M2 Bradley	28
1	FIST-V	7
1	HMMWV/50C	15
1	M106A1	6
1	D7 Dozer	1
1	ACE	3
2	M1A1/2	28
2	M2 Bradley	30
2	HMMWV/50C	15
2	M106A1	6
2	CEV	4
2	FIST-V	5
2	D7 Dozer	1
2	ACE	3
3	M1A1/2	58
3	M106A1	6
3	FIST-V	8
3	D7 Dozer	1
3	ACE	3
4	M109A3 Paladin	72
4	MLRS	36
4	FIST-V	3
5	Avenger	12
5	Apaches	12
5	BSFV	8
5	A-10	4
5	M3	12

Table 6: NEA Blue Forces

ENEMY FORCES

The Threat Maneuver forces are moving south in two echelons, one brigade leading and one in trail. Both brigades are comprised of three task forces (6 total), two of which are armored battalions with an attached mechanized infantry company. The third task force in each brigade is an armored company. The first brigade leads the deliberate attack, while the second follows up looking to exploit any weaknesses found by the first. The Red forces have the following weapons and vehicles in their deliberate attack.

Task Force Designation	Vehicle Type	Number per Task Force	Total Number
1&4	T-72	82	164
1&4	BMP-2	56	112
1&4	BTR-60	6	12
1&4	BRDM-AT	8	16
1&4	RPG-9	18	36
1&4	SA-13	23	26
1&4	ZSU-23-4	9	18
1&4	Hokum	2	4
1&4	120mm Mortar	14	28
1&4	2S6	12	24
1&4	MLRS	6	12
2&5	T-72	82	164
2&5	BMP-2	56	112
2&5	BTR-60	6	12
2&5	BRDM-AT	8	16
2&5	RPG-9	18	36
2&5	SA-13	23	26
2&5	ZSU-23-4	9	18
2&5	Hokum	2	4
2&5	120mm Mortar	14	28
2&5	2S6	12	24
2&5	MLRS	6	12
3&6	T-72	24	48
3&6	BMP-2	10	20
3&6	BRDM-AT	3	3
3&6	RPG-9	18	36
3&6	SA-13	13	26
3&6	ZSU-23-4	6	12
3&6	Hokum	3	6
3&6	120mm Mortar	14	28
3&6	2S6	12	24
3&6	MLRS	6	12

Table 7: NEA Red Forces

CONCEPT OF THE OPERATION

The mission for the Blue Forces is to stop the Threat advance to the south. During the Threat advance, Blue Forces must not allow the first brigade to punch through the prepared defenses opening an alley for the second brigade of Red Forces to exploit. The primary thrust of the battle for the Blue Forces is to fix and destroy the first echelon of the attack, while deep battle helps attrit the approaching second echelon where they will also be fixed and destroyed by the Blue defense.

Blue Forces are in a strong, fixed defensive posture with two balanced task forces abreast and one task force in reserve. Minefields, tank ditches, and smoke have been employed to slow the attack and strategically funnel the enemy's main effort into kill zone.

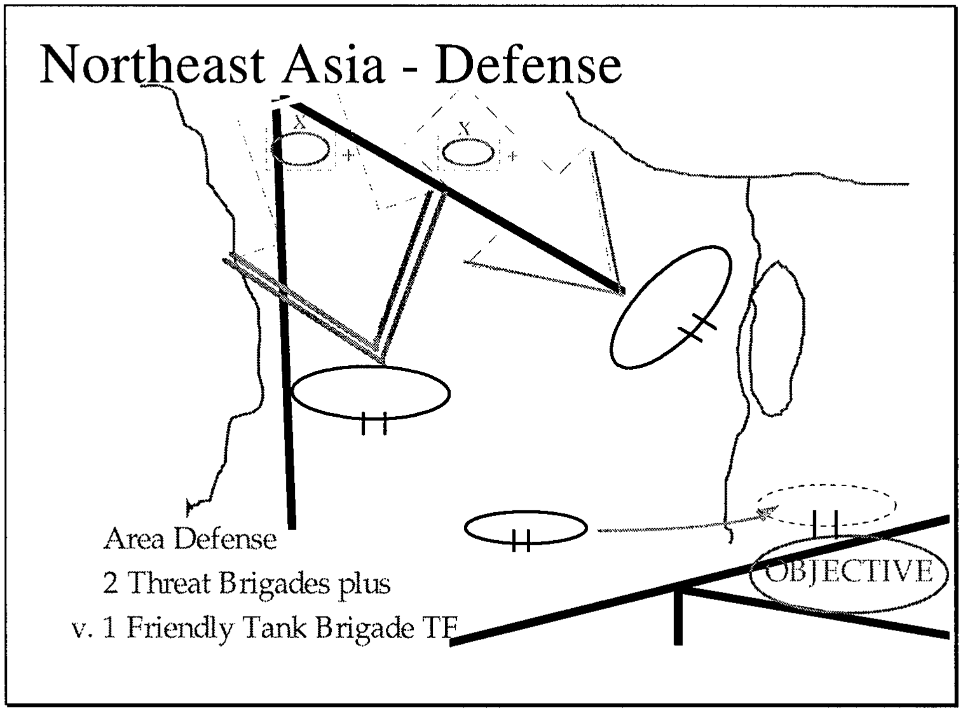


Figure 3 - Defensive Scenario NEA

Since Blue Forces are in the defense, friendly actions are dependent on the actions of the enemy forces. In addition, the concept of the friendly defensive operations is built largely on the anticipation of enemy actions. In this scenario, Blue Forces anticipate the Threat Maneuver Forces to move southward using Soviet offensive doctrine. Friendly Forces anticipate a staged column formation on the approach, which once engaged will break up and form into a Soviet style attack formation. Additionally, Blue Forces anticipate this first echelon of Threat to be followed closely by a second. Since Blue Forces anticipate this second echelon, they are ready to launch a deep battle against the second Threat Brigade with artillery and air support once recognized.

The Blue Forces expect to engage the first echelon relatively unscathed and in full strength. Once the initial Threat Forces are defeated, the friendly forces must be prepared to finish off the remainder of the second brigade, which should be heavily attrited by the time they reach the primary engagement area.

MEASURES OF EFFECTIVENESS AND RESULTS

In the analysis of this design, four measures of combat effectiveness were selected to evaluate the different design alternatives:

1. Average Tank Engagement Range
2. Force Exchange Ratio
3. Time to Attrit Red Forces to 50% (inverted later)
4. The Blue Force Strength over time

The performance of these MOE's were evaluated, and only those that are statistically significant are identified. Results were then normalized on the base case battalion with 58 M1A1 tanks. Each MOE is a more is better criteria. For overall performance of a criteria, offensive performance was weighted twice as much as defense, portraying the importance and likelihood of armor units in offensive operations. Each MOE and the performance in the simulation analysis follow.

TANK ENGAGEMENT RANGE

In was believed, prior to the study, that M1A2 tanks and the larger organizations would engage enemy armored vehicles at greater ranges. This measure of effectiveness was simply the mean engagement range by M1 tanks against T-72, BMP-2, BRDM and BTR-60 Red vehicles.

Analysis of the results did in fact reveal that M1A2 tanks defeated enemy vehicles at an

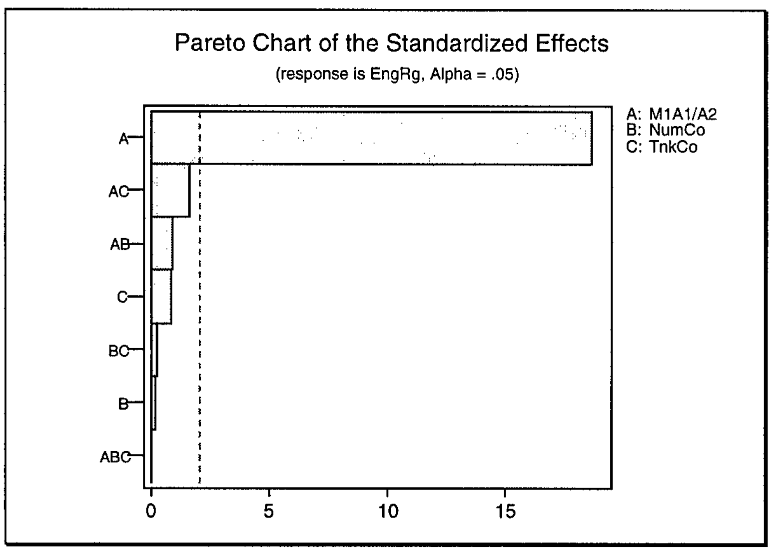


Figure 4 - Pareto Chart of Engagement Range Effects

average of 74 meters farther than M1A1 tanks in the defense. In the offense, there was no statistically significant distinction. Overall, the difference in engagement range showed only a 3.1% change in average engagement range, and the M1A2's did not appear as a significant positive or negative factor anywhere else in the study at this time. This lack of difference may be primarily due to the way constructive simulations such as Janus do not adequately portray enhanced command and control systems. Figure 4 illustrates the positive effect of M1A2 tanks on engagement range. The bar that extends to the right of the dashed lines portrays effects that were significant. No conclusions can be drawn on those effects to the left of the line.

Because the overall effect was minimal in the experiment, the overall importance in later computation of relative effect was reduced to 10%.

FORCE EXCHANGE RATIO

Force Exchange Ratio (FER) is defined as the ratio of red losses over blue, relative to their starting strength.

$$FER = \frac{\#\text{ofRed Losses} / \#\text{Red at Start}}{\#\text{ofBlue Losses} / \#\text{Blue at Start}}$$

This ratio is more robust than a loss exchange ratio because it takes into account the initial force strength. There was a more drastic change in FER in the offense scenario than in the defense,

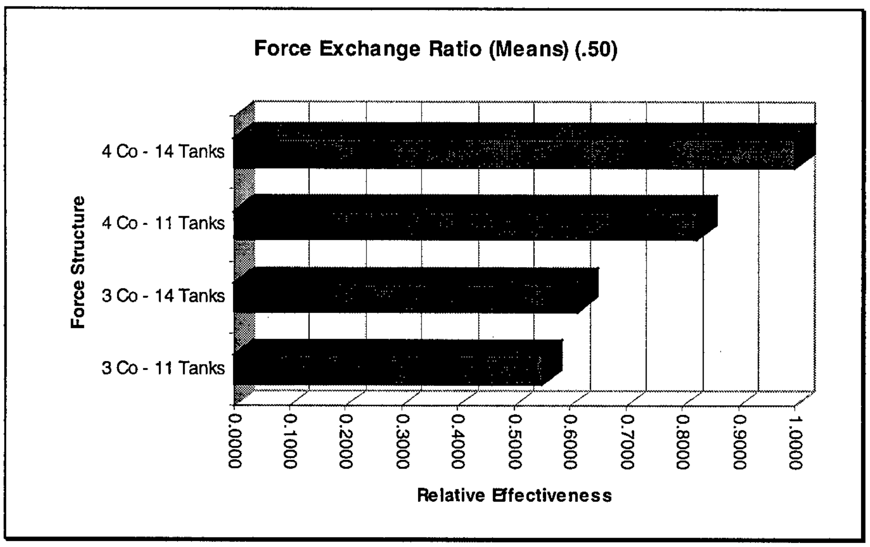


Figure 5 - Force Exchange Ratio Relative Effectiveness
(relative to the base case of 58 tanks)

particularly between the alternatives with four versus three companies. Figure 5 shows the relative FER of each of the organization configuration alternatives. Most notable is the 20% drop in FER between 4 companies of 11 tanks and 3 companies of 14. This change in FER was statistically significant in both the offense and defense, with the number of companies being the most significant factor, followed by the number of tanks in the company. Figure 6 shows the Pareto chart for effects in both the offense and the defense scenarios.

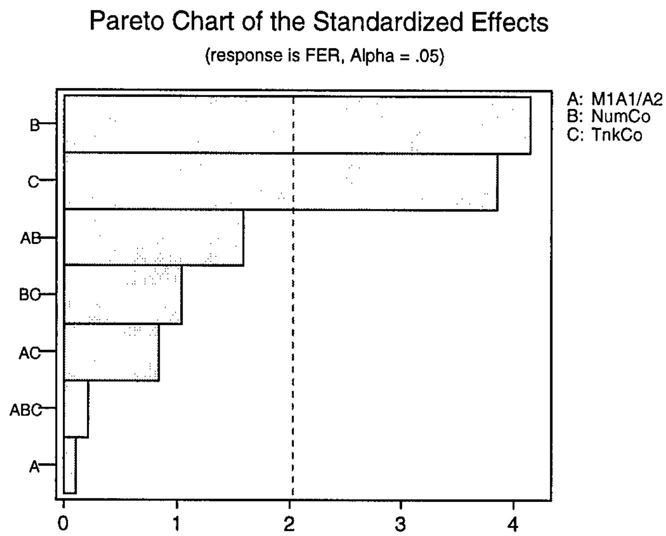


Figure 6 - Pareto Charts of Significance of FER

Force Exchange Ratio is the most robust MOE used in the study, and was therefore weighted at half of the overall operational effectiveness.

TIME TO ATTRIT ENEMY FORCES

Another important measure in analysis was the amount of time it took the task force to attrit the red forces to 50% strength, in both the offense and the defense. In order to later combine each of the three major MOE's, values for the 50% attrition time were inverted to make it a *"more is better"* criteria. While there was not a drastic change between the four alternative configurations, the relative change in performance can be seen in figure 7.

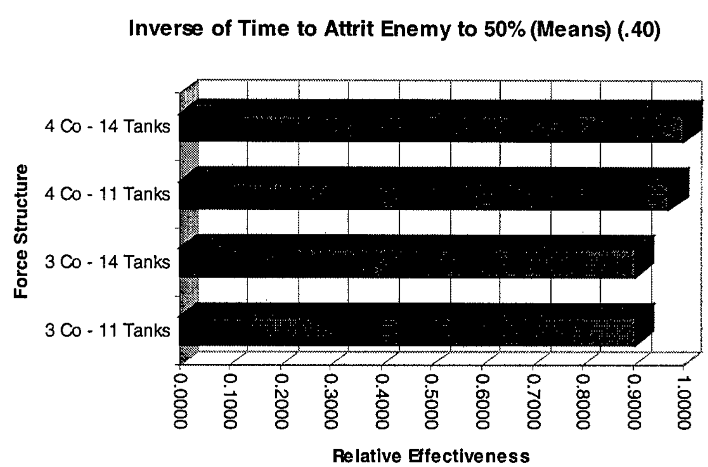


Figure 7 - Relative time to attrit red forces

Probably because this study is largely one of force-on-force attrition, the alternatives with the most tanks forward did better than fewer tanks in the defense. Here, the number of tanks in the company proved to be slightly more significant than the number of companies. This MOE was weighted at 40% of the overall relative operational effectiveness numbers.

FORCE STATUS OVER TIME

While not originally a measure of effectiveness for this study, it is interesting to examine the force levels of different alternatives as the battle progressed. As can be seen in figures 8 and 9, the largest deltas are evident in alternatives with three companies rather than four. This was much more evident in the offense than in the defense, which evolved into a battle of attrition.

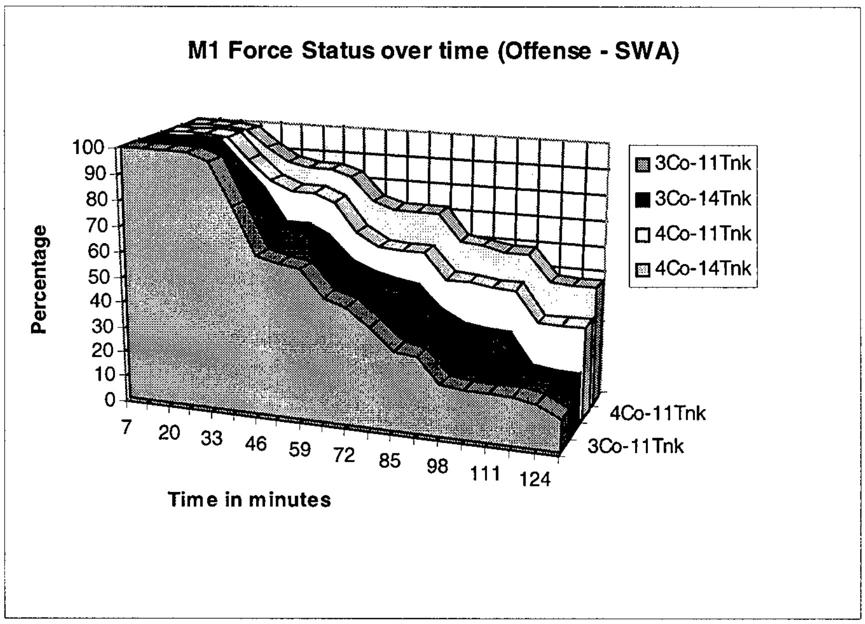


Figure 8 - Blue Force Status over time (Offense)

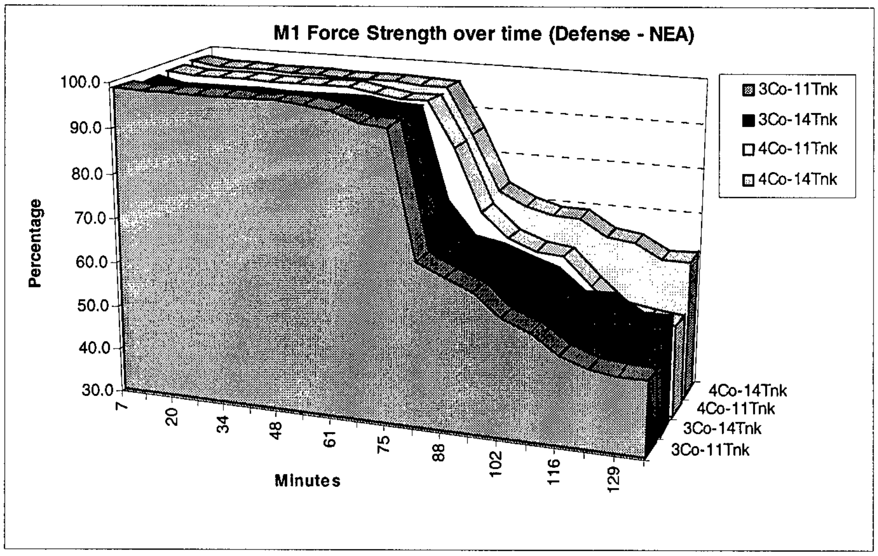


Figure 9 - Blue Force Status over time (Defense)

RELATIVE EFFECTIVENESS

In order to analyze each alternative configuration with a single measure, each of the three MOEs and the offense and defense data were combined into an overall measure of operational relative effectiveness. Offense was weighted twice as important as defensive results as the true spirit of an armor battalion is offensive. An armored battalion is not deployed to defend terrain, but to rapidly seize terrain. Force Exchange Ratio, being the mostly robust MOE used, comprised 50% of the total. Time to Attrit Red to half strength made up the next 40%, and the Average tank Engagement Range of each design point comprised the last 10% of the total. The totals of all these MOEs were combined into a relative effectiveness score, benchmarked by the existing configuration of 58 tanks. Figure 10 shows the overall effectiveness of each alternative. From 58 to 46 tanks, there is a 10% decrease in performance. From 46 to 44 tanks, there is a 15% drop, then a 4% drop to 35 tanks. Clearly, the most evident drop in total performance is between 46 and 44 tanks, with a 10% loss for just 2 tanks.

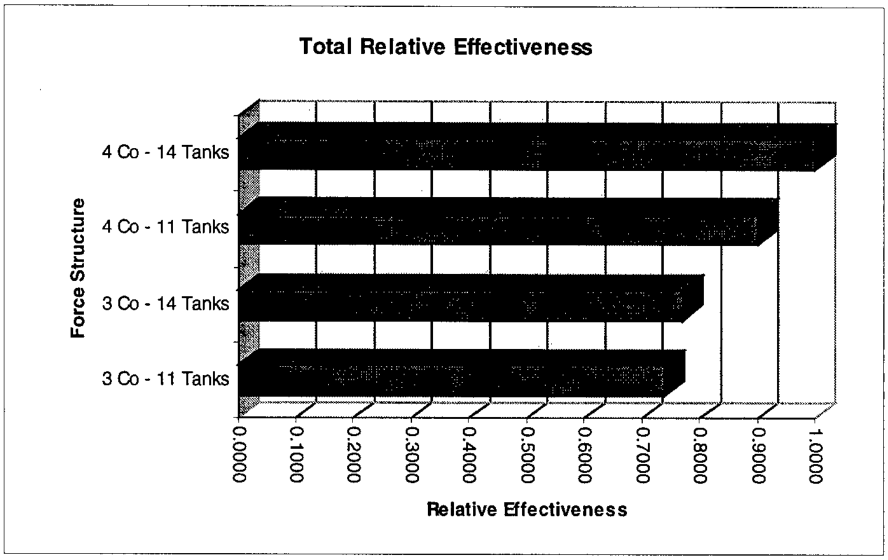


Figure 10 - Overall Relative Effectiveness

The most statistically significant factor in the overall effectiveness was the number of companies, followed by the number of tanks in the company as the second most significant factor. Figure 11 shows the overall impact of both factors.

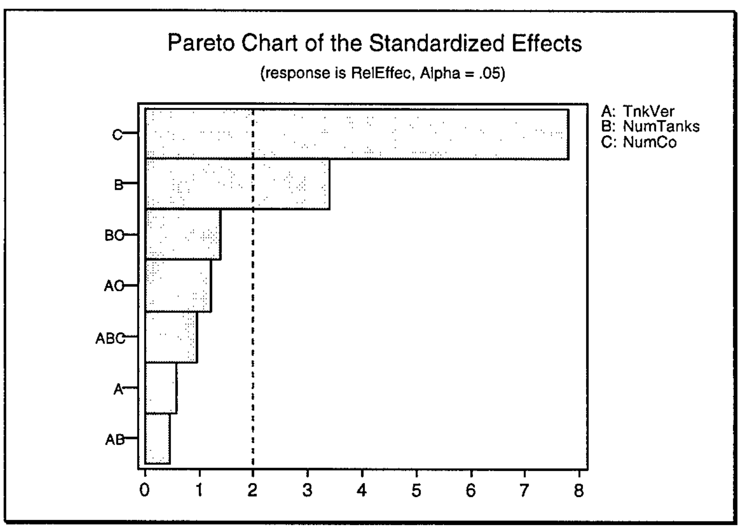


Figure 11 - Pareto Chart of Total Relative Effectiveness

SENSITIVITY ANALYSIS

A sensitivity analysis of the weights for each MOE was conducted to examine if the recommended solution was sensitive to change of the weight values. Obviously, the 58 tank battalion is the dominant solution, but we wanted to know if the emerging 46 battalion alternative would ever fall below the 44 tank battalion. Figure 12 shows that as weight is shifted from FER to Time to Attrit, that the 46 tank battalion (4 companies of 11 tanks) remains dominant.

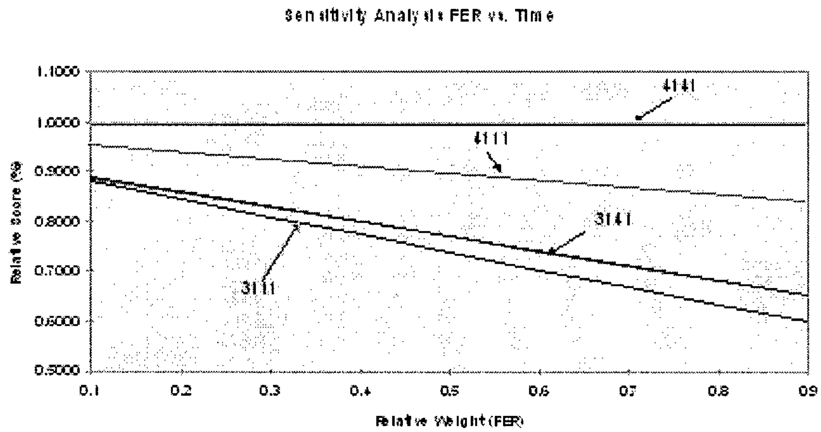


Figure 12 - Sensitivity Analysis Graph

COST ANALYSIS

When looking at each of the factors and components in our recommended force structure, cost obviously becomes a factor. There are several things that we have to account for when addressing cost. For our analysis, we concentrated on costs from Operations and Maintenance (O&M).

Number of tanks per Battalion	Total O&M Cost per Battalion
58	$8,334,600
46	$6,610,200
44	$6,322,800
35	$5,029,500

Table 8 - O&M Cost Data

According to the Army's FY95 Combat Systems Cost Report, O&M cost for one M1A1 tank for one year is approximately $143,700.00.[1] Table 8 shows how cost varies with the number of tanks in an armor battalion.

From this table, it is evident that the fewer tanks per battalion the

[1] Army VAMOSC FY95 Cost Report, Volume 2 - Combat Systems.

less the O&M costs will be. However, along with losing tanks, we are losing combat effectiveness. This is obviously detrimental to the objectives stated earlier in our analysis.

Trade-Off Analysis

When considering the trade-off between cost and effectiveness, we want to minimize costs while maintaining at least 75% of the present effectiveness. In order to do this, we looked at the O&M costs of each alternative as well as the cost effectiveness of each alternative. The cost effectiveness is simply the amount of money that the Army would have to spend to bring a reduced armor battalion up to the combat effectiveness of the current 58 tank battalion. The following chart in figure 13 shows this comparison.

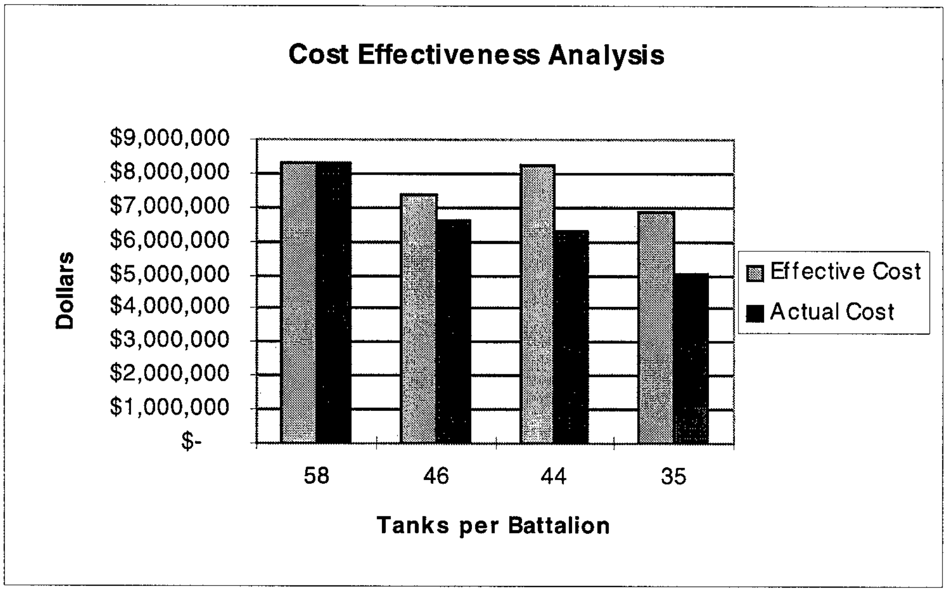


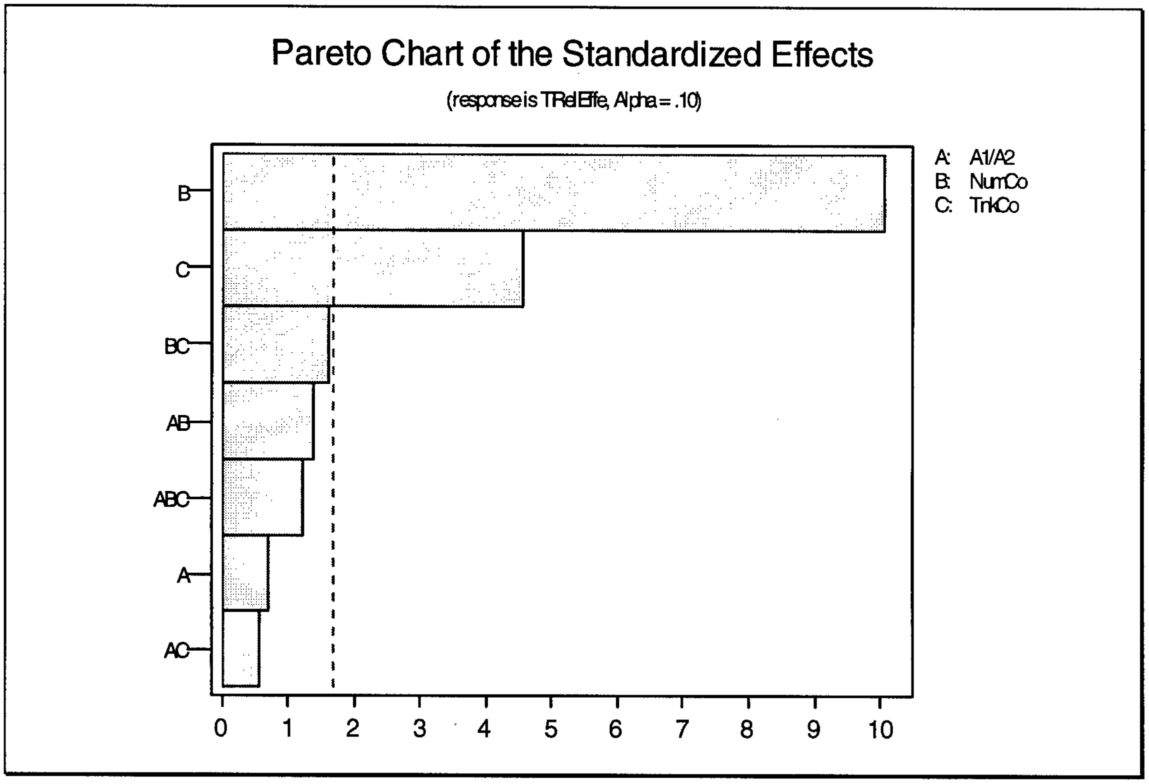
Figure 13: Cost Analysis

From this table, we can see that the 46 tank battalion is the best alternative looking at the cost data. The 35 tank battalion has a lower cost, but its combat effectiveness falls well below the accepted 75% cut-off. Basically, we would have to deploy two battalions of the 35 tank alternative to meet the combat effectiveness of the current system.

CONCLUSION AND RECOMMENDATION

Based on the analysis, the design team recommends the 4 companies of 11 tanks alternative. This alternative gives us the best overall effectiveness at the lowest effective cost. As a result, by adopting the 4 of 11 alternative, an armor battalion can save money as well as maintain most of its current combat effectiveness. It is also important to note that the combat simulation modeled down to company size resolution. While the report mentions reducing a tank platoon from 4 to 3 tanks as a method for reducing company size from 14 to 11, we did not explicitly model platoons, and cannot account for the results of such a change at the platoon level.

APPENDIX A
Armor Battalion Force Structure in Force XXI

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Fractional Factorial Fit

TOTAL RELATIVE EFFECT *(COMBINED OFFENSE AND DEFENSE)*

Estimated Effects and Coefficients for **TRelEffe**

Term	Effect	Coef	StDev Coef	T	P
Constant		0.873016	0.006324	138.05	0.000
A1/A2	-0.008806	-0.004403	0.006324	-0.70	0.491
NumCo	**0.127311**	**0.063655**	**0.006324**	**10.07**	**0.000**
TnkCo	**0.057474**	**0.028737**	**0.006324**	**4.54**	**0.000**
A1/A2*NumCo	-0.017390	-0.008695	0.006324	-1.37	0.179
A1/A2*TnkCo	-0.007147	-0.003573	0.006324	-0.57	0.576
NumCo*TnkCo	0.020396	0.010198	0.006324	1.61	0.117
A1/A2*NumCo*TnkCo	-0.015445	-0.007723	0.006324	-1.22	0.231

Analysis of Variance for TRelEffe

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	3	0.195888	0.195888	0.065296	40.82	0.000
2-Way Interactions	3	0.007695	0.007695	0.002565	1.60	0.208
3-Way Interactions	1	0.002386	0.002386	0.002386	1.49	0.231
Residual Error	32	0.051189	0.051189	0.001600		
Pure Error	32	0.051189	0.051189	0.001600		
Total	39	0.257157				

Unusual Observations for TRelEffe

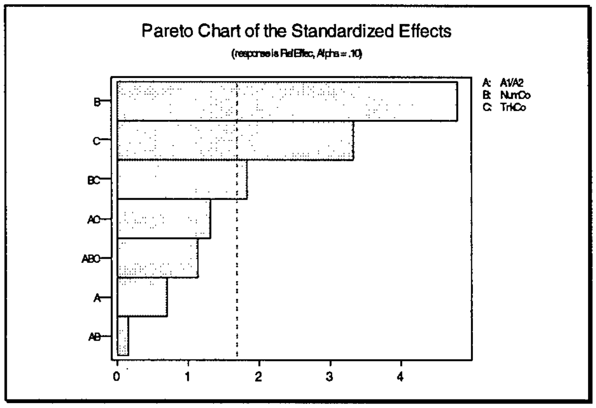
Obs	TRelEffe	Fit	StDev Fit	Residual	St Resid
32	1.06082	0.95121	0.01789	0.10961	3.06R
37	0.89135	0.81946	0.01789	0.07189	2.01R

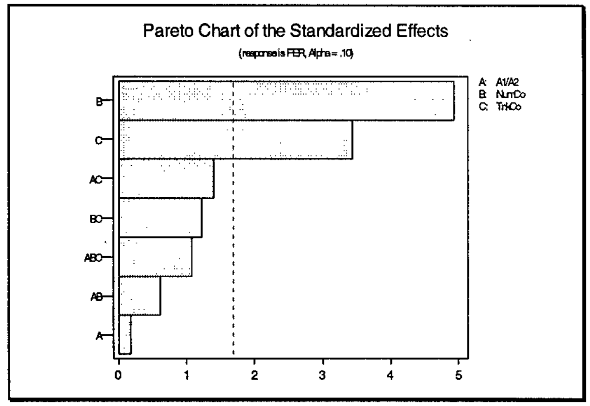
R denotes an observation with a large standardized residual

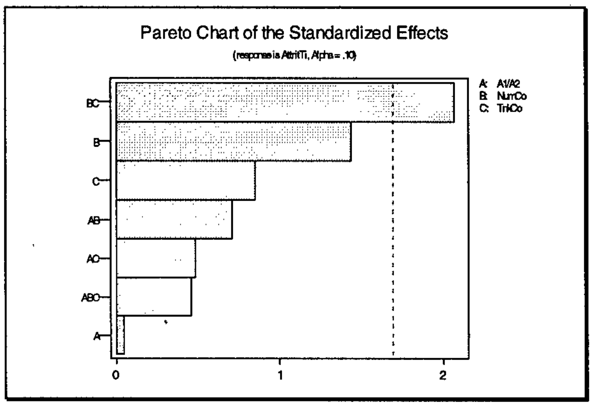
Means for TRelEffe

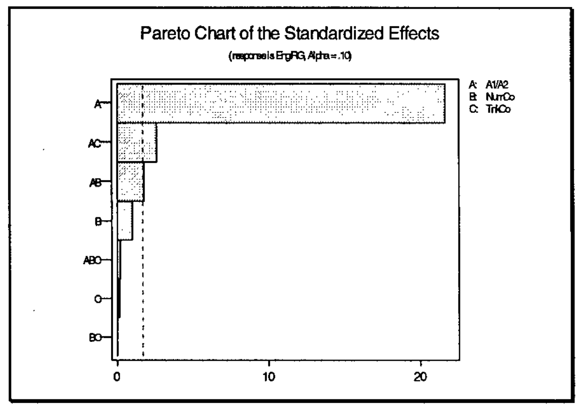
			Mean	StDev
A1/A2				
-1			0.8774	0.008943
1			0.8686	0.008943
NumCo				
-1			0.8094	0.008943
1			0.9367	0.008943
TnkCo				
-1			0.8443	0.008943
1			0.9018	0.008943
A1/A2*	NumCo			
-1	-1		0.8051	0.012648
1	-1		0.8137	0.012648
-1	1		0.9498	0.012648
1	1		0.9236	0.012648
A1/A2*	TnkCo			
-1	-1		0.8451	0.012648
1	-1		0.8434	0.012648
-1	1		0.9097	0.012648
1	1		0.8938	0.012648
NumCo*	TnkCo			
-1	-1		0.7908	0.012648
1	**-1**		**0.8977**	**0.012648**
-1	**1**		**0.8279**	**0.012648**
1	1		0.9756	0.012648
A1/A2*	NumCo*	TnkCo		
-1	-1	-1	0.7907	0.017887
1	-1	-1	0.7910	0.017887
-1	1	-1	0.8995	0.017887
1	1	-1	0.8959	0.017887
-1	-1	1	0.8195	0.017887
1	-1	1	0.8363	0.017887
-1	1	1	1.0000	0.017887
1	1	1	0.9512	0.017887

APPENDIX B (Defense-NEA)
Armor Battalion Force Structure in Force XXI









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Fractional Factorial Fit

Estimated Effects and Coefficients for **FER**

Term	Effect	Coef	StDev Coef	T	P
Constant		0.88888	0.01301	68.33	0.000
A1/A2	-0.00465	-0.00232	0.01301	-0.18	0.859
NumCo	**0.12835**	**0.06418**	**0.01301**	**4.93**	**0.000**
TnkCo	**0.08955**	**0.04477**	**0.01301**	**3.44**	**0.002**
A1/A2*NumCo	0.01575	0.00787	0.01301	0.61	0.549
A1/A2*TnkCo	-0.03625	-0.01813	0.01301	-1.39	0.173
NumCo*TnkCo	0.03175	0.01588	0.01301	1.22	0.231
A1/A2*NumCo*TnkCo	-0.02785	-0.01392	0.01301	-1.07	0.292

Analysis of Variance for FER

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	3	0.245145	0.245145	0.081715	12.07	0.000
2-Way Interactions	3	0.025702	0.025702	0.008567	1.27	0.303
3-Way Interactions	1	0.007756	0.007756	0.007756	1.15	0.292
Residual Error	32	0.216597	0.216597	0.006769		
Pure Error	32	0.216597	0.216597	0.006769		
Total	39	0.495200				

Unusual Observations for FER

Obs	FER	Fit	StDev Fit	Residual	St Resid
32	1.29500	0.98720	0.03679	0.30780	4.18R

R denotes an observation with a large standardized residual

Means for FER

			Mean	StDev
A1/A2				
-1			0.8912	0.01840
1			0.8865	0.01840
NumCo				
-1			0.8247	0.01840
1			0.9530	0.01840
TnkCo				
-1			0.8441	0.01840
1			0.9337	0.01840
A1/A2*	NumCo			
-1	-1		0.8349	0.02602
1	-1		0.8145	0.02602
-1	1		0.9475	0.02602
1	1		0.9586	0.02602
A1/A2*	TnkCo			
-1	-1		0.8283	0.02602
1	-1		0.8599	0.02602
-1	1		0.9541	0.02602
1	1		0.9132	0.02602
NumCo*	TnkCo			
-1	-1		0.7958	0.02602
1	**-1**		**0.8924**	**0.02602**
-1	**1**		**0.8536**	**0.02602**
1	1		1.0137	0.02602
A1/A2*	NumCo*	TnkCo		
-1	-1	-1	0.8018	0.03679
1	-1	-1	0.7898	0.03679
-1	1	-1	0.8548	0.03679
1	1	-1	0.9300	0.03679
-1	-1	1	0.8680	0.03679
1	-1	1	0.8392	0.03679
-1	1	1	1.0402	0.03679
1	1	1	0.9872	0.03679

Estimated Effects and Coefficients for **EngRG**

Term	Effect	Coef	StDev Coef	T	P
Constant		2.71345	0.002596	1045.25	0.000
A1/A2	**0.11230**	**0.05615**	**0.002596**	**21.63**	**0.000**
NumCo	0.00510	0.00255	0.002596	0.98	0.333
TnkCo	0.00090	0.00045	0.002596	0.17	0.863
A1/A2*NumCo	**-0.00910**	**-0.00455**	**0.002596**	**-1.75**	**0.089**
A1/A2*TnkCo	**0.01350**	**0.00675**	**0.002596**	**2.60**	**0.014**
NumCo*TnkCo	-0.00010	-0.00005	0.002596	-0.02	0.985
A1/A2*NumCo*TnkCo	-0.00110	-0.00055	0.002596	-0.21	0.834

Analysis of Variance for EngRG

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	3	0.126381	0.126381	0.0421270	156.28	0.000
2-Way Interactions	3	0.002651	0.002651	0.0008836	3.28	0.033
3-Way Interactions	1	0.000012	0.000012	0.0000121	0.04	0.834
Residual Error	32	0.008626	0.008626	0.0002696		
Pure Error	32	0.008626	0.008626	0.0002696		
Total	39	0.137670				

Unusual Observations for EngRG

Obs	EngRG	Fit	StDev Fit	Residual	St Resid
5	2.61200	2.64340	0.00734	-0.03140	-2.14R

R denotes an observation with a large standardized residual

Means for EngRG

			Mean	StDev
A1/A2				
-1			2.657	0.003671
1			2.770	0.003671
NumCo				
-1			2.711	0.003671
1			2.716	0.003671
TnkCo				
-1			2.713	0.003671
1			2.714	0.003671
A1/A2*	NumCo			
-1	-1		2.650	0.005192
1	-1		2.772	0.005192
-1	1		2.664	0.005192
1	1		2.768	0.005192
A1/A2*	TnkCo			
-1	-1		2.664	0.005192
1	-1		2.762	0.005192
-1	1		2.651	0.005192
1	1		2.777	0.005192
NumCo*	TnkCo			
-1	-1		2.710	0.005192
1	-1		2.716	0.005192
-1	1		2.711	0.005192
1	1		2.716	0.005192
A1/A2*	NumCo*	TnkCo		
-1	-1	-1	2.657	0.007343
1	-1	-1	2.764	0.007343
-1	1	-1	2.670	0.007343
1	1	-1	2.761	0.007343
-1	-1	1	2.643	0.007343
1	-1	1	2.779	0.007343
-1	1	1	2.659	0.007343
1	1	1	2.774	0.007343

Estimated Effects and Coefficients for **AttritTi**

Term	Effect	Coef	StDev Coef	T	P
Constant		104.285	1.564	66.68	0.000
A1/A2	-0.140	-0.070	1.564	-0.04	0.965
NumCo	-4.490	-2.245	1.564	-1.44	0.161
TnkCo	-2.650	-1.325	1.564	-0.85	0.403
A1/A2*NumCo	2.220	1.110	1.564	0.71	0.483
A1/A2*TnkCo	1.520	0.760	1.564	0.49	0.630
NumCo*TnkCo	**-6.470**	**-3.235**	**1.564**	**-2.07**	**0.047**
A1/A2*NumCo*TnkCo	1.440	0.720	1.564	0.46	0.648

Analysis of Variance for AttritTi

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	3	272.02	272.02	90.67	0.93	0.439
2-Way Interactions	3	491.00	491.00	163.67	1.67	0.192
3-Way Interactions	1	20.74	20.74	20.74	0.21	0.648
Residual Error	32	3130.68	3130.68	97.83		
Pure Error	32	3130.68	3130.68	97.83		
Total	39	3914.43				

Unusual Observations for AttritTi

Obs	AttritTi	Fit	StDev Fit	Residual	St Resid
7	115.000	94.960	4.423	20.040	2.27R
36	86.600	106.160	4.423	-19.560	-2.21R

R denotes an observation with a large standardized residual

Means for AttritTi

			Mean	StDev
A1/A2				
-1			104.36	2.212
1			104.22	2.212
NumCo				
-1			106.53	2.212
1			102.04	2.212
TnkCo				
-1			105.61	2.212
1			102.96	2.212
A1/A2*	NumCo			
-1	-1		107.71	3.128
1	-1		105.35	3.128
-1	1		101.00	3.128
1	1		103.08	3.128
A1/A2*	TnkCo			
-1	-1		106.44	3.128
1	-1		104.78	3.128
-1	1		102.27	3.128
1	1		103.65	3.128
NumCo*	TnkCo			
-1	-1		104.62	3.128
1	**-1**		**106.60**	**3.128**
-1	**1**		**108.44**	**3.128**
1	1		97.48	3.128
A1/A2*	NumCo*	TnkCo		
-1	-1	-1	105.84	4.423
1	-1	-1	103.40	4.423
-1	1	-1	107.04	4.423
1	1	-1	106.16	4.423
-1	-1	1	109.58	4.423
1	-1	1	107.30	4.423
-1	1	1	94.96	4.423
1	1	1	100.00	4.423

Estimated Effects and Coefficients for **RelEffec**

Term	Effect	Coef	StDev Coef	T	P
Constant		0.914095	0.007432	122.99	0.000
A1/A2	0.010387	0.005193	0.007432	0.70	0.490
NumCo	**0.071400**	**0.035700**	**0.007432**	**4.80**	**0.000**
TnkCo	**0.049446**	**0.024723**	**0.007432**	**3.33**	**0.002**
A1/A2*NumCo	0.002296	0.001148	0.007432	0.15	0.878
A1/A2*TnkCo	-0.019576	-0.009788	0.007432	-1.32	0.197
NumCo*TnkCo	**0.027106**	**0.013553**	**0.007432**	**1.82**	**0.078**
A1/A2*NumCo*TnkCo	-0.016965	-0.008482	0.007432	-1.14	0.262

Analysis of Variance for RelEffec

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	3	0.076507	0.0765067	0.025502	11.54	0.000
2-Way Interactions	3	0.011232	0.0112324	0.003744	1.69	0.188
3-Way Interactions	1	0.002878	0.0028781	0.002878	1.30	0.262
Residual Error	32	0.070705	0.0707054	0.002210		
Pure Error	32	0.070705	0.0707054	0.002210		
Total	39	0.161323				

Unusual Observations for RelEffec

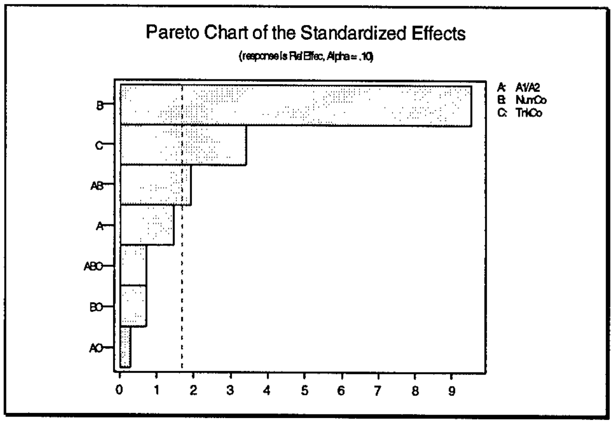
Obs	RelEffec	Fit	StDev Fit	Residual	St Resid
24	0.88753	0.97614	0.02102	-0.08861	-2.11R
32	1.16225	0.97614	0.02102	0.18611	4.43R

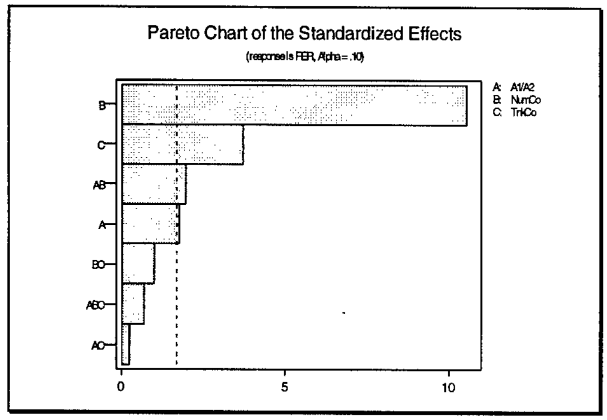
R denotes an observation with a large standardized residual

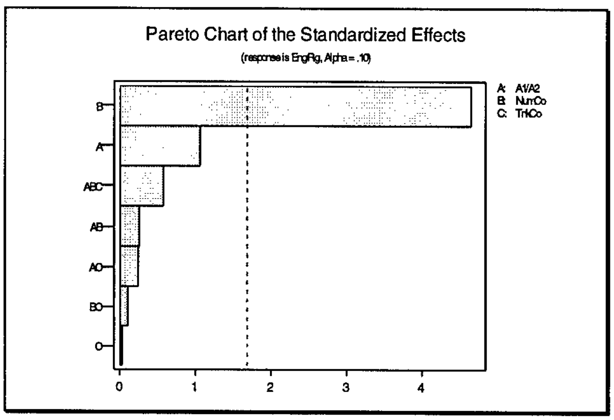
Means for RelEffec

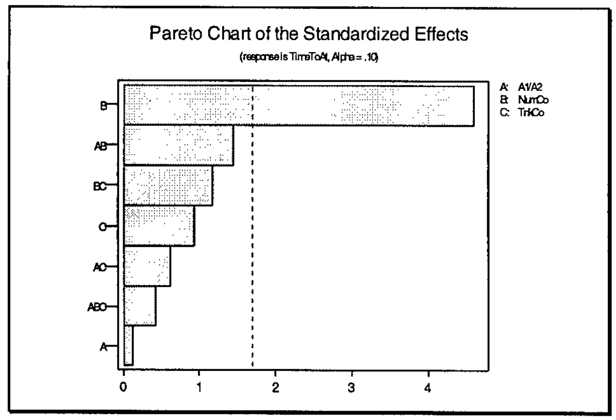
			Mean	StDev
A1/A2				
-1			0.9089	0.01051
1			0.9193	0.01051
NumCo				
-1			0.8784	0.01051
1			0.9498	0.01051
TnkCo				
-1			0.8894	0.01051
1			0.9388	0.01051
A1/A2*	NumCo			
-1	-1		0.8743	0.01486
1	-1		0.8824	0.01486
-1	1		0.9435	0.01486
1	1		0.9561	0.01486
A1/A2*	TnkCo			
-1	-1		0.8744	0.01486
1	-1		0.9044	0.01486
-1	1		0.9434	0.01486
1	1		0.9342	0.01486
NumCo*	TnkCo			
-1	-1		0.8672	0.01486
1	-1		0.9115	0.01486
-1	1		0.8896	0.01486
1	1		0.9881	0.01486
A1/A2*	NumCo*	TnkCo		
-1	-1	-1	0.8619	0.02102
1	-1	-1	0.8726	0.02102
-1	1	-1	0.8869	0.02102
1	1	-1	0.9361	0.02102
-1	-1	1	0.8868	0.02102
1	-1	1	0.8923	0.02102
-1	1	1	1.0000	0.02102
1	1	1	0.9761	0.02102

APPENDIX C (Offense - SWA)
Armor Battalion Force Structure in Force XXI









Worksheet size: 100000 cells

Retrieving worksheet from file: D:\CAPSTONE\TANK\OFF-SWA.MTW
Worksheet was saved on 3/12/1997

Fractional Factorial Fit

Estimated Effects and Coefficients for **FER**

Term	Effect	Coef	StDev Coef	T	P
Constant		0.92030	0.02337	39.37	0.000
A1/A2	**-0.08240**	**-0.04120**	**0.02337**	**-1.76**	**0.088**
NumCo	**0.49380**	**0.24690**	**0.02337**	**10.56**	**0.000**
TnkCo	**0.17380**	**0.08690**	**0.02337**	**3.72**	**0.001**
A1/A2*NumCo	**-0.09200**	**-0.04600**	**0.02337**	**-1.97**	**0.058**
A1/A2*TnkCo	0.01100	0.00550	0.02337	0.24	0.815
NumCo*TnkCo	0.04680	0.02340	0.02337	1.00	0.324
A1/A2*NumCo*TnkCo	-0.03200	-0.01600	0.02337	-0.68	0.499

Analysis of Variance for FER

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	3	2.80835	2.80835	0.93612	42.83	0.000
2-Way Interactions	3	0.10775	0.10775	0.03592	1.64	0.199
3-Way Interactions	1	0.01024	0.01024	0.01024	0.47	0.499
Residual Error	32	0.69936	0.69936	0.02186		
Pure Error	32	0.69936	0.69936	0.02186		
Total	39	3.62570				

Unusual Observations for FER

Obs	FER	Fit	StDev Fit	Residual	St Resid
10	0.86300	0.59320	0.06611	0.26980	2.04R
37	1.02800	0.71060	0.06611	0.31740	2.40R

R denotes an observation with a large standardized residual

Means for FER

			Mean	StDev
A1/A2				
-1			0.9615	0.03306
1			0.8791	0.03306
NumCo				
-1			0.6734	0.03306
1			1.1672	0.03306
TnkCo				
-1			0.8334	0.03306
1			1.0072	0.03306
A1/A2*	NumCo			
-1	-1		0.6686	0.04675
1	-1		0.6782	0.04675
-1	1		1.2544	0.04675
1	1		1.0800	0.04675
A1/A2*	TnkCo			
-1	-1		0.8801	0.04675
1	-1		0.7867	0.04675
-1	1		1.0429	0.04675
1	1		0.9715	0.04675
NumCo*	TnkCo			
-1	-1		0.6099	0.04675
1	**-1**		**1.0569**	**0.04675**
-1	**1**		**0.7369**	**0.04675**
1	1		1.2775	0.04675
A1/A2*	NumCo*	TnkCo		
-1	-1	-1	0.6266	0.06611
1	-1	-1	0.5932	0.06611
-1	1	-1	1.1336	0.06611
1	1	-1	0.9802	0.06611
-1	-1	1	0.7106	0.06611
1	-1	1	0.7632	0.06611
-1	1	1	1.3752	0.06611
1	1	1	1.1798	0.06611

Estimated Effects and Coefficients for **EngRg**

Term	Effect	Coef	StDev Coef	T	P
Constant		2.36127	0.007826	301.71	0.000
A1/A2	0.01663	0.00832	0.007826	1.06	0.296
NumCo	**-0.07293**	**-0.03646**	**0.007826**	**-4.66**	**0.000**
TnkCo	0.00045	0.00023	0.007826	0.03	0.977
A1/A2*NumCo	0.00403	0.00201	0.007826	0.26	0.799
A1/A2*TnkCo	-0.00382	-0.00191	0.007826	-0.24	0.809
NumCo*TnkCo	-0.00169	-0.00085	0.007826	-0.11	0.914
A1/A2*NumCo*TnkCo	-0.00902	-0.00451	0.007826	-0.58	0.568

Analysis of Variance for EngRg

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	3	0.055950	0.0559499	0.0186500	7.61	0.001
2-Way Interactions	3	0.000336	0.0003363	0.0001121	0.05	0.987
3-Way Interactions	1	0.000815	0.0008145	0.0008145	0.33	0.568
Residual Error	32	0.078399	0.0783992	0.0024500		
Pure Error	32	0.078399	0.0783992	0.0024500		
Total	39	0.135500				

Unusual Observations for EngRg

Obs	EngRg	Fit	StDev Fit	Residual	St Resid
17	2.28240	2.39296	0.02214	-0.11056	-2.50R
27	2.19910	2.30868	0.02214	-0.10958	-2.48R

R denotes an observation with a large standardized residual

Means for EngRg

			Mean	StDev
A1/A2				
-1			2.353	0.01107
1			2.370	0.01107
NumCo				
-1			2.398	0.01107
1			2.325	0.01107
TnkCo				
-1			2.361	0.01107
1			2.362	0.01107
A1/A2*	NumCo			
-1	-1		2.391	0.01565
1	-1		2.404	0.01565
-1	1		2.314	0.01565
1	1		2.335	0.01565
A1/A2*	TnkCo			
-1	-1		2.351	0.01565
1	-1		2.371	0.01565
-1	1		2.355	0.01565
1	1		2.368	0.01565
NumCo*	TnkCo			
-1	-1		2.397	0.01565
1	-1		2.325	0.01565
-1	1		2.399	0.01565
1	1		2.324	0.01565
A1/A2*	NumCo*	TnkCo		
-1	-1	-1	2.393	0.02214
1	-1	-1	2.400	0.02214
-1	1	-1	2.309	0.02214
1	1	-1	2.342	0.02214
-1	-1	1	2.390	0.02214
1	-1	1	2.408	0.02214
-1	1	1	2.320	0.02214
1	1	1	2.328	0.02214

Estimated Effects and Coefficients for **TimeToAt**

Term	Effect	Coef	StDev Coef	T	P
Constant		79.745	0.6163	129.39	0.000
A1/A2	-0.140	-0.070	0.6163	-0.11	0.910
NumCo	**-5.680**	**-2.840**	**0.6163**	**-4.61**	**0.000**
TnkCo	-1.140	-0.570	0.6163	-0.92	0.362
A1/A2*NumCo	1.770	0.885	0.6163	1.44	0.161
A1/A2*TnkCo	-0.750	-0.375	0.6163	-0.61	0.547
NumCo*TnkCo	1.450	0.725	0.6163	1.18	0.248

A1/A2*NumCo*TnkCo	0.520	0.260	0.6163	0.42	0.676

Analysis of Variance for TimeToAt

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	3	335.816	335.816	111.939	7.37	0.001
2-Way Interactions	3	57.979	57.979	19.326	1.27	0.301
3-Way Interactions	1	2.704	2.704	2.704	0.18	0.676
Residual Error	32	486.220	486.220	15.194		
Pure Error	32	486.220	486.220	15.194		
Total	39	882.719				

Unusual Observations for TimeToAt

Obs	TimeToAt	Fit	StDev Fit	Residual	St Resid
33	76.5000	84.2000	1.7432	-7.7000	-2.21R

R denotes an observation with a large standardized residual

Means for TimeToAt

			Mean	StDev
A1/A2				
-1			79.82	0.8716
1			79.67	0.8716
NumCo				
-1			82.59	0.8716
1			76.91	0.8716
TnkCo				
-1			80.32	0.8716
1			79.18	0.8716
A1/A2*	NumCo			
-1	-1		83.54	1.2327
1	-1		81.63	1.2327
-1	1		76.09	1.2327
1	1		77.72	1.2327
A1/A2*	TnkCo			
-1	-1		80.01	1.2327
1	-1		80.62	1.2327
-1	1		79.62	1.2327
1	1		78.73	1.2327
NumCo*	TnkCo			
-1	-1		83.88	1.2327
1	-1		76.75	1.2327
-1	1		81.29	1.2327
1	1		77.06	1.2327
A1/A2*	NumCo*	TnkCo		
-1	-1	-1	84.20	1.7432
1	-1	-1	83.56	1.7432
-1	1	-1	75.82	1.7432
1	1	-1	77.68	1.7432
-1	-1	1	82.88	1.7432
1	-1	1	79.70	1.7432
-1	1	1	76.36	1.7432
1	1	1	77.76	1.7432

Estimated Effects and Coefficients for **RelEffec**

Term	Effect	Coef	StDev Coef	T	P
Constant		0.83194	0.009629	86.40	0.000
A1/A2	-0.02800	-0.01400	0.009629	-1.45	0.156
NumCo	**0.18322**	**0.09161**	**0.009629**	**9.51**	**0.000**
TnkCo	**0.06550**	**0.03275**	**0.009629**	**3.40**	**0.002**
A1/A2*NumCo	**-0.03708**	**-0.01854**	**0.009629**	**-1.93**	**0.063**
A1/A2*TnkCo	0.00528	0.00264	0.009629	0.27	0.786

NumCo*TnkCo	0.01369	0.00684	0.009629	0.71	0.482
A1/A2*NumCo*TnkCo	-0.01392	-0.00696	0.009629	-0.72	0.475

Analysis of Variance for RelEffec

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	3	0.386446	0.386446	0.128815	34.74	0.000
2-Way Interactions	3	0.015899	0.015899	0.005300	1.43	0.252
3-Way Interactions	1	0.001939	0.001939	0.001939	0.52	0.475
Residual Error	32	0.118668	0.118668	0.003708		
Pure Error	32	0.118668	0.118668	0.003708		
Total	39	0.522953				

Unusual Observations for RelEffec

Obs	RelEffec	Fit	StDev Fit	Residual	St Resid
10	0.82119	0.70935	0.02723	0.11183	2.05R
33	0.83558	0.71948	0.02723	0.11609	2.13R
37	0.87407	0.75209	0.02723	0.12198	2.24R

R denotes an observation with a large standardized residual

Means for RelEffec

			Mean	StDev
A1/A2				
-1			0.8459	0.01362
1			0.8179	0.01362
NumCo				
-1			0.7403	0.01362
1			0.9235	0.01362
TnkCo				
-1			0.7992	0.01362
1			0.8647	0.01362
A1/A2*	NumCo			
-1	-1		0.7358	0.01926
1	-1		0.7449	0.01926
-1	1		0.9561	0.01926
1	1		0.8910	0.01926
A1/A2*	TnkCo			
-1	-1		0.8158	0.01926
1	-1		0.7825	0.01926
-1	1		0.8760	0.01926
1	1		0.8533	0.01926
NumCo*	TnkCo			
-1	-1		0.7144	0.01926
1	**-1**		**0.8840**	**0.01926**
-1	**1**		**0.7662**	**0.01926**
1	1		0.9631	0.01926
A1/A2*	NumCo*	TnkCo		
-1	-1	-1	0.7195	0.02723
1	-1	-1	0.7094	0.02723
-1	1	-1	0.9122	0.02723
1	1	-1	0.8557	0.02723
-1	-1	1	0.7521	0.02723
1	-1	1	0.7804	0.02723
-1	1	1	1.0000	0.02723
1	1	1	0.9263	0.02723